HMD BASED VIRTUAL ENVIRONMENTS FOR MILITARY TRAINING - TWO CASES

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ABSTRACT

This paper reports on two cases in which Head Mounted Display (HMD) based Virtual Environments (VE) are applied to military training. The first case deals with Forward Air Controller training, while the second case is aimed at Stinger training. Both applications are subjects of study within the VE research program of the TNO Physics and Electronics Laboratory and the TNO Human Factors Research Institute.

For the Forward Air Controller (FAC) training application a feasibility study was recently performed. Based upon a task and training analysis, a prototype FAC training simulator was developed and evaluated. Evaluation results have encouraged both the Dutch armed forces and other NATO countries (United Kingdom, Belgium) to seriously consider the HMD based FAC simulator as a useful and effective training tool. The paper describes the simulator prototype and evaluation results, including the human factors issues that were addressed in this study.

The Stinger training application is still in an early stage of development. Instigated by a demand of the Royal Netherlands Air Force, the research is focused on finding a suitable concept for a mobile training device. The paper describes a planned project (to start in 1998) that includes the development of an experimental system in order to evaluate several design alternatives. The evaluation has as a goal to determine how human performance is affected by the type of display system that is used, the overall system latency and the tracking accuracy.

INTRODUCTION

Beginning with the emergence of the technology, the TNO Physics and Electronics Laboratory has been researching the application of advanced Virtual Environment (VE) technology to military training and command & control problems [1]. One of the focal points in this research program is the use of Head Mounted Display (HMD) technology to provide a visual environment that fully surrounds the user, the main advantage of HMDs being their much smaller size then conventional projection display devices.

The use of HMD technology in virtual environments for training simulation has always been recognised to be of great potential. However, to date TNO has no knowledge of operational military training devices based upon this technology. The application of VE technology to the training of Forward Air Controllers and to the training of Stinger teams are likely to be among first cases that will change this.

In the remainder of this paper we provide a description of two research projects that are carried out on the application of HMD based virtual environment systems to the Forward Air Controller training problem and the training of Stinger teams.

Forward Air Controller Training Simulator

Initiated by a demand for more effective training tools at the Netherlands Integrated Air Ground Operations School (NIAGOS), the use of VE technology for training Forward Air Controllers was made the subject of a feasibility study. In a co-operative effort between the Royal Netherlands Army, the TNO Physics and Electronics Laboratory and the TNO Human Factors research institute, a study was carried out to determine whether an HMD based training simulator would be a valid and feasible solution to improve training effectiveness.

The Forward Air Controller (FAC) plays an important role in Close Air Support (CAS) operations. CAS operations are performed when air support is requested to attack enemy units that are in close proximity to friendly units. The task for the FAC is to guide the CAS pilots in the final stage of their mission such that they engage the correct enemy targets, without endangering friendly forces.

CAS pilots are briefed in advance on their mission objective and all relevant mission data. The brief includes information on the target position and describes the position of nearby friendly units, and possible threats the pilot may

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encounter. Based upon the specified target position, the pilot programs his navigation system that essentially guides him *roughly* to the target, taking into consideration the fact that there will be a certain error in the specified target position, that the navigation system has a limited accuracy, and that the target may be moving.

At this point the FAC comes into the picture. Based upon briefing data, the pilot will be able to fly to the target area. The FAC then takes over to make sure that the *eyes* of the pilot are guided onto the correct target and that the pilot is aware of the position of friendly units in the target area such that they are not endangered.

To accomplish his task, the FAC chooses an observation position (OP) in the terrain from where the target area can be well observed, while at the same time an unobstructed view is provided in the direction where the plane is expected to show up. From the OP, the FAC continuously observes the enemy units, most specifically the designated target, the friendly units and (when in sight) the plane.

The FAC provides guidance cues to the CAS pilot via a UHF radio connection. This radio communication has to conform to a NATO standard procedure for FAC operation.

In situations where it is difficult to find clear marking points in the terrain, the FAC has several ways to create artificial reference points: special light reflectors or lamps, smoke grenades, and flares can be used for this purpose. Most CAS planes are also equipped to detect laser target designator signals. The FAC then uses a laser target designator to point out the target by putting the laser spot upon it.

CURRENT TRAINING PRACTICE

A typical initial FAC training course currently takes three to four weeks. The first part of the course, about a week, covers theory: air operations in general, CAS operations, NATO standard FAC procedures, map handling, radio operation, radio procedures, etc. After this, the practical issues are divided into two parts: low threat and high threat operations.

Low threat FAC operation is commonly considered to be relatively easy. A FAC who is qualified for high threat operations, is also assumed to be qualified for low threat. Low threat operation is only trained by using aerial photographs as a visualisation tool. The 'pilot' (usually an instructor) is given an aerial photograph of the target area as it would be seen from the plane when circling above the area. The FAC trainee has prepared the scenario with a map and possibly with observations in the real terrain. The goal of the exercise is then for the trainee to 'talk' the eyes of the pilot onto the correct position on the aerial photograph.

Most training effort is put into high threat operations. Training for high threat FAC operations is currently facilitated in three ways in addition to theoretical instruction:

- Review of video and voice recordings that are taken from a cockpit during FAC operations (so-called HUD tapes);
- Classroom simulation by using a scale model of a target area and a toy plane;
- Live training runs.

HUD tapes and scale model simulation are only used in the first week of the course. The remainder of the course is filled with live training runs to exercise high threat training as much as possible. Low threat scenarios are usually not trained with live training sorties.

Training Bottlenecks

Analysis of the current FAC training practice shows a number of bottlenecks that reduce both the effectiveness and the efficiency of current training:

- Moving from classroom training to live training for high threat operation proves to be too big a step, as witnessed by the bad results of the first series of live training runs;
- Limited availability of flying hours for live training sorties often severely impedes the training course (due to, for example, cost restrictions, capacity restrictions, flying restrictions, weather restrictions and bird activity restrictions.)

- Live training is the only effective training tool for high threat FAC operation, but it is a very expensive tool to use to this end.

These bottlenecks have been taken as the starting point for the hypothesis that a new simulation tool will solve them, and improve both the effectiveness and efficiency of FAC training.

Problem Approach

To test the hypothesis that an HMD-based training simulator would solve the above mentioned bottlenecks, the following approach has been followed:

- A *task analysis* of FAC operation has been performed;
- A *training objective analysis* for initial FAC training has been performed;
- The training objectives have been *mapped on training tools*, to find out which training objectives should be reached with the simulator;
- A set of initial *user and system requirements* has been defined for the FAC simulator;
- A *prototype* simulator has been built;
- an *evaluation* of the prototype simulator has been performed to test the hypothesis and assess the feasibility of the FAC simulator.

Simulator Solution

The FAC task analysis and training objective analysis results indicate that FAC training can be improved by providing a simulator tool that aims to contribute to the following training objectives:

- Planning of a FAC operation:
  - Creating a mission brief;
  - Selection of a suitable OP;
- Pilot guidance:
  - Communication procedure with the pilot;
  - Recognising and adjusting the plane's flight path;
  - Observation of the environment;
- Battle damage assessment.

These training objectives are currently covered by either classroom instruction that lacks realism or by live training that is not cost-effective.

The essence of the FAC simulator is that it shall provide a training tool that bridges the gap between the standard classroom instruction and the live training. The simulator shall enable the FAC trainees to experience and exercise FAC procedures in a realistic way (i.e., with realistic time pressure and realistic visual perception tasks) before they are exposed to real planes.

It is claimed that an HMD-based virtual environment system embedded in a distributed interactive simulation network (see Figure 1) will provide this bridge between theory and practice.

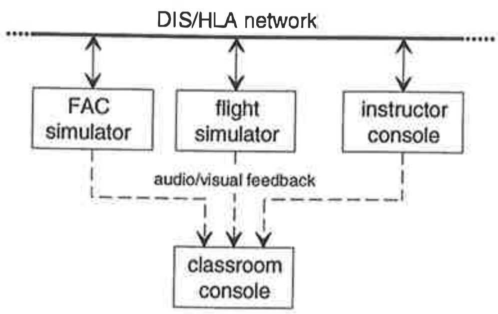

Figure 1. The conceptual structure of the FAC training simulator system.

The need for an HMD (see Figure 2) is motivated by the requirement that the FAC must be able to fully observe the environment around him, since CAS plane and target are usually in opposite direction. An HMD is advantageous over other projection displays in the fact that it provides visual feedback covering the entire 360° azimuth and 180° elevation field of regard in a very small and affordable device. Because of this, the HMD is very suitable for tasks that rely on spatial perception of an environment, as is the case with FAC operation.

Evaluation Method

The simulator solution presented in the previous section was prototyped within TNO's Electronic Battlespace Facility [2]. This prototype enabled us to evaluate whether the proposed HMD based training simulator solution is a valid and acceptable solution. A concise description of the prototype can be found in [3]. For the course of this paper, it is relevant to note that:

- The HMD used for the prototype is an n-Vision HiRes stereoscopic display device that displays 1280x1024 pixels in each eye. The optics of the HMD project the images onto a field of view of 63° horizontally by 34° vertically per eye, with a 50% overlap between the two images. This yields a resolution of 1.6 arcmin per pixel.
- The HMD is tracked by an InterSense IS-300 PRO tracking device that continuously reports the viewing angles of the FAC trainee. The IS-300 uses inertial technology to determine the FAC's viewing direction.
- The stereo images for the HMD are provided by a Silicon Graphics Onyx^2 with a single Infinite Reality pipe. Average frame rate was 30 to 60 Hz.
- Figure 3 depicts a typical database scene as seen by the FAC.
- While performing simulator exercises, the classroom console provides a simultaneous view of the scene as seen by the FAC and the pilot as well as a map view of the target area. These images are presented on large retro projection screens.

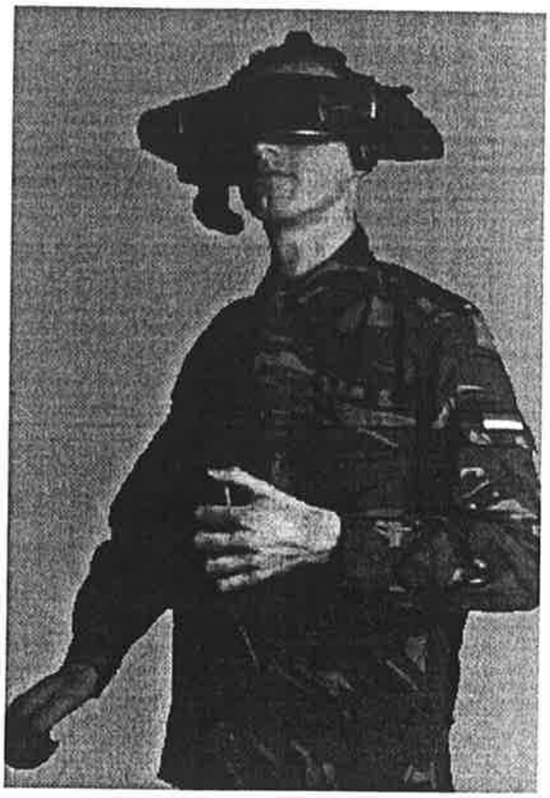

Figure 2. The FAC simulator uses a Head Mounted Display to immerse the FAC in the working environment.

Prototype evaluation has been done in five sessions. In the first two sessions, only FAC instructors were involved, whose primary aim it was to assess whether it is possible to simulate FAC operations with the simulator, and secondly whether the system is as suitable as an instruction tool.

After the positive outcome of the first two evaluation sessions, the prototype was to be further evaluated in three regular FAC courses as given by NIAGOS. The objective of these sessions was to determine how inexperienced trainees would cope with the system and what the learning transfer would be. In the first week of the course, after trainees had caught up with theory, simulation training was performed during a single day. Practical constraints limited the use of the simulator to only a single day per course - ideally the simulator should be used during the whole course.

The evaluation is limited in the fact that it has been mainly qualitative in nature. A lot of issues require further evaluation and quantification. However, the evaluation that has been performed enables us to answer the main question of this feasibility study, namely whether the HMD based FAC training simulator can be a tool to resolve current FAC training bottlenecks.

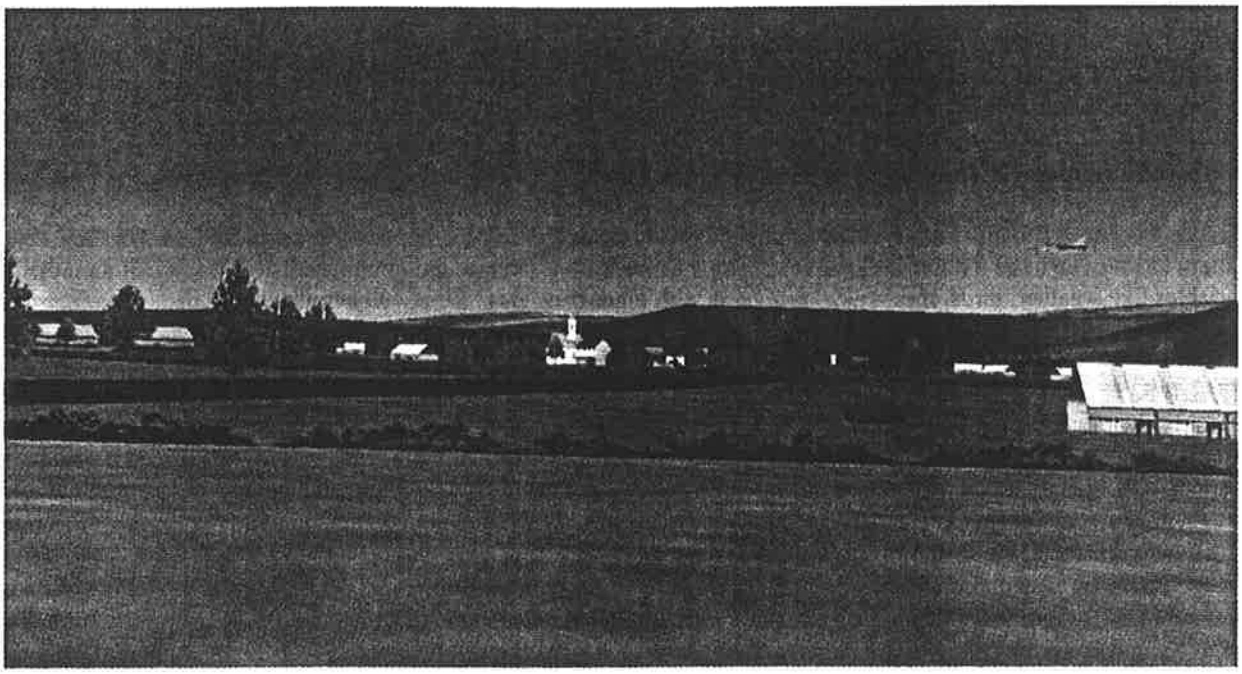

Figure 3. A typical view on the virtual target area as seen by the FAC through the HMD

Evaluation Results

The main outcome of the evaluation sessions is that the FAC simulator proves to be a valid simulation of FAC operation and that it can be used effectively to improve FAC training.

Improved Training Effectiveness

The first observation is that the use of the FAC simulator enhances training effectiveness. Taking into account that only a single day of simulator training was integrated in the course, it was already observed that the initial live training runs after simulator training were more successful than in courses without simulator training.

The main reason for the fact that the simulator enhances training effectiveness, is that the simulator is a more suitable tool to train novice FACs than exercising on live training runs. When using only live sorties as a training tool, the trainees will need many runs to get to a certain minimum capability level. Many of these runs will fail. Using the FAC simulator for this stage of training demonstrates it to be a more effective way to push the trainees to a desired initial capability level. The reason behind this is that simulator training is much more controllable than live training - the level of the exercises can be matched with the capabilities of the individual FAC.

Improved Training Feedback

The use of a classroom console has proven to be a very valuable instruction tool. The correlation of the FAC's view with the flight simulator view in particular provides trainees good insight into how a pilot perceives the terrain, thus learning which cues are best used for visual guidance.

The use of the scenario freeze and scenario playback feature also demonstrated the value of simulation over live training. During live training, there is little opportunity to evaluate runs. Only after the planes have returned to base, the HUD tapes can be reviewed and the pilots can give their comments on the runs. Simulation, on the other hand, allows direct feedback on the trainee's behaviour.

The improved feedback also facilitates the instructor in the evaluation of a trainee's performance. It is observed that this evaluation is currently done in a very subjective and informal way. The evaluation could be pushed to a more objective level by introducing automated support for it. The available DIS/HLA network data and communications recording could be a source of information to extract objective scoring data.

Improved Training Flexibility

Having the control to fly sorties in the simulated world at any desired time, any desired place, and in any desired pattern has proven to be a relief for FAC instructors. Current FAC courses are continuously impeded by uncontrollable variables like weather, birds, mechanical problems with planes, etc., which are fully controlled in the synthetic training environment.

Human Performance Issues

Several important human factors issues have been observed during the evaluation sessions of the prototype:

- All trainees accept the HMD based simulator as a useful and pleasant tool - no simulator sickness or discomfort was reported;
- To obtain visual aircraft detection ranges that are realistic (5 to 8 kilometres), the aircraft model is scaled up 8 times (and gradually scaled down to a 1:1 size as it approaches the FAC);
- Trainees are indeed able to give visual guidance control to the pilot by perceiving the position and orientation of the plane;
- Trainees have some difficulties in getting the right orientation within the terrain (this problem has been reduced by displaying a heading reading at the bottom of the screen).

Technical Issues

From a technical point of view, the experiments with the FAC simulator prototype have taught us the following lessons:

- The InterSense tracking system is superior over often used electromagnetic tracking systems, considering both accuracy and speed - a comparison between the two has shown considerably improved perception capabilities for target detection, due to absence of lag and jitter;
- A large amount of system development effort will have to go into database development - a diversity of high quality databases is a prerequisite for a fully operational training simulator.
- The distributed architecture of the FAC simulator, relying on the standard DIS/HLA concepts, provides ample opportunities for the development of a fully functional and extendible simulator.

Simulator Opportunities

The current study has only touched upon FAC simulation to a limited extent: the use of simulation for initial training of high threat FAC operations. However, simulation brings a lot more opportunities. The full list of applications includes:

- Personnel selection;
- Initial training;
- Currency training;
- Currency testing;
- Mission rehearsal.

FACs who already have a combat ready status, will need training to keep up their currency. Currency training with the simulator will be a good approach for this purpose. Within NATO, combat ready FAC's have to perform six successful runs every half year. A combat ready FAC has once been reported to need eighteen runs to perform six successful ones. It would have been much more cost effective if these twelve unsuccessful runs would have been performed in a simulator.

For currency training, the FAC simulator can be connected to a real flight simulator, possibly situated at a remote air base, via the DIS/HLA network. Thus, both FAC and CAS pilot can be trained to keep up currency.

Once simulation is an accepted tool in FAC currency training and has demonstrated to decrease the number of currency test runs that is required to fulfil the NATO currency requirement, simulation may well become a mandatory part of currency tests.

As the application of the simulator is extended to currency training and even currency tests, the requirements for the simulator are also extended. More complex scenarios need to be simulated, including threat handling, multiple CAS planes and more difficult conditions like night CAS operations.

For mission rehearsal application, not only the complexity of the scenario is increased, but also the need for a geospecific database of the mission area is put forward, as is the simulation of dynamic threats of various kinds (enemy aircraft, ground forces, radar, etc.)

All these opportunities indicate that FAC simulation provides ample means to increase the capabilities of FACs, while in the end a strong reduction of cost can be effected due to a reduced number of live training runs that is required. At the same time, the live training runs that are still performed - and necessary - are used more effectively.

FURTHER WORK

The FAC simulator has been received with great enthusiasm within the FAC community. The fact that both research and development on this subject have only been partly touched upon, imply that a lot of work remains to be done. Here are some of the topics:

- Conduct a more quantitative study of the impact of the simulator on training effectiveness and efficiency;
- Find ways to solve the terrain orientation problem by displaying auxiliary information in the HMD - without introducing negative training transfer;
- Introduce objective trainee evaluation concepts and automated support for this to push the current subjective scoring methods to a more objective level;
- Develop a fully operational FAC simulator.
- Allow for more complex scenarios, such as threat handling, and night CAS procedures;
- Extend the concept of the simulator to airborne FAC, heli-FAC, and forward artillery observers (FO).

CONCLUSION

The main conclusion of our FAC study has been that introduction of an HMD based simulator for FAC training is feasible and will greatly enhance training effectiveness and efficiency. Evaluation of the prototype system within a series of three FAC courses has shown that the simulator is accepted by the trainees as a useful tool to learn with and by the instructors as a useful tool to teach with.

By filling the gap between classroom training and live training, the FAC simulator solves all bottlenecks inherent to current training practice. The advantages and the enthusiasm of the users that have been observed during the evaluation of the prototype makes TNO believe that FAC simulation will be among the first applications of HMD based simulation systems that will come to an operational status.

STINGER TEAM TRAINER

Stinger is a man-portable, shoulder-fired, ground-to-air missile weapon system. It is mainly used to provide air defence against high-speed, low-level, ground-attack aircraft and helicopter. The system is operational with the Royal Netherlands armed forces (all three of Air Force, Army and Navy) and the armed forces of many other nations.

Back in 1992, the TNO Physics and Electronics Laboratory developed a simple concept demonstrator that illustrates how HMD-based virtual environment technology can be applied to Stinger training (see Figure 4). It took until 1995 for the Royal Netherlands Air Force to catch up with this concept and investigate whether a VE based simulator could benefit Stinger training. This resulted in a paperwork study by TNO that revealed the opportunities of a VE Stinger trainer, but at the same time raised a number of unresolved questions with respect to the optimum design of such a VE Stinger trainer [4].

To answer the questions that have been raised by the paper work study in 1995, a new project has been planned to go on starting in 1998. The problem statement and planned approach of this project is described in the following sections.

Figure 4. - The HMD based Stinger Trainer concept demonstrator as built by TNO in 1992 (background image is image as seen in the HMD)

Current Training Practice

The Dutch armed forces currently have the following training devices available for Stinger training:

- A dome-based trainer (see Figure 5) that provides a slide-projected terrain and up to two moving targets on a 20 metres diameter dome;
- A video-equiped training weapon system that is used in conjuction with live flying exercises;
- The Stinger Troop Proficiency Trainer (STPT), a training weapon system with a small visor display that shows a virtual terrain with virtual targets.

Novice Stinger personnel receive their initial training in the Stinger dome trainer. Combat readiness is then ensured in exercises with the video-based trainer and in live training at a shooting range. The STPT is supposed to be used for currency training (in practice, the STPT is not used at all).

Training Bottlenecks

The Royal Netherlands Air Force have indicated a requirement for better currency training tools. The new currency training tool shall:

- Provide a broad range of training scenarios with complexity varying between novice level and extended air defence exercise levels;
- Enable simulation of all Stinger part tasks;
- Enable full team training;
- Be mobile.

None of the three training devices mentioned above fulfils these requirements. Subject of study is whether HMD-based virtual environment technology can do this job. An intrinsic issue here is that an HMD based Stinger trainer assures mobility while still providing a full 360 degrees field of view.

Problem Approach

Based upon earlier work for Stinger training, the question whether a VE Stinger trainer is a feasible and valid solution to the Stinger training requirements has been reduced to first get answers on the following questions:

a. To what specifications shall a mobile Stinger team training system adhere with respect to the following critical issues:

   - The type of display system;
   - The tracking system performance;
   - The end-to-end system latency.

b. What is the expected learning transfer for a VE technology based mobile Stinger team training system?

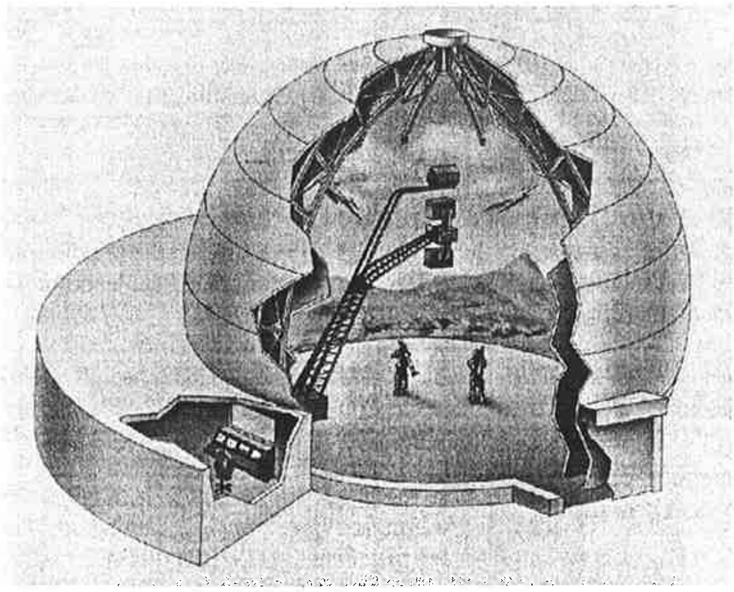

Figure 5. The Dutch armed forces currently use a dome-based training device for Stinger training

Display System

The most crucial and unclear aspect about the Stinger team training system is the way to setup the display system. We think of the following options to configure the display system:

- Stereo immersive HMD;
- Stereo see-through HMD;
- Stereo see-through HMD combined with a visor display to obtain high precision target display;
- Mono see-through HMD on the left eye combined with a visor display used by the right eye;
- Projection screen;
- Projection screen combined with a visor display to obtain high precision target display.

The main issue to deal with here is the physical interaction between the head and the weapon system. In normal operation, the gunner will put his head against the visor. An HMD is a very elegant device to display a large surrounding environment with a yet small device, but it makes the physical contact between head and weapon system impossible.

The latter three options listed above do enable the gunner to lay the head against the weapon. Most notably the configuration with a mono see-through HMD on the left eye and the visor display on the right eye is an interesting option to investigate.

Tracking System

A tracking system is required to measure the position and orientation of both the HMD and the weapon. Given the small measures of the visor, this is a very accurate task. The tracking system shall therefore be:

- Accurate;
- Noise free;
- Fast.

It shall be determined what requirements are to be laid upon the performance of the tracking system with respect to these aspects. In addition to this, the characteristics of the tracking system can influence the operational restrictions of the training device. Some tracking systems put restrictions on the operating environment, or are very difficult to set up - this can conflict with the mobility requirement.

System Latency

Aiming a Stinger weapon system on a target is a perceptual motor task that can lead to unstable control in a simulator if end-to-end system latency is too large. The maximum latency that still provides acceptable simulation validity shall be determined.

Learning Transfer

The answers to the questions of how to setup the system design as posed in the previous sections are only of value if the VE simulator concept will be bring satisfactory learning transfer at all. The learning transfer with respect to the following Stinger tasks shall therefore be measured:

- Target detection;
- Target identification;
- Aiming and firing;
- Command and control processes;
- Using weapon system peripherals;
- Team operation.

Evaluation Method

The issues raised in the previous section will be dealt with by building an experimental Stinger team training system. The experimental system shall provide full functionality to simulate all relevant Stinger tasks and at the same time be flexible to enable the setup of different configurations with respect to the display system, the tracking performance and the end-to-end system latency.

The experimental system will then be used for evaluations in three stages:

- Component level evaluation;
- Part task evaluation;
- Integral evaluation.

Component Level Evaluation

The component level evaluation addresses the quality of the individual components used in the experimental system. The following aspects are investigated:

- The quality of the display systems;
- The quality of the tracking system;
- The ability to position the head with respect to the weapon system;
- The end-to-end system latency.

The results of this stage are required to interpret the results and identify involved causes in the remainder of the evaluations.

Part Task Evaluation

The part task evaluation aims at measuring human performance with respect to Stinger part tasks when using a specific configuration of the experimental Stinger trainer. Part task times and accuracies will be measured.

Integral Evaluation

The integral evaluation aims at measuring the learning transfer by determining human performance when performing a Stinger attack as a complete procedure. Hit-rates and procedure timing will be measured for a group of subjects on a typical series of Stinger training exercises. Part of the group will be subject to a number of different configurations of the experimental Stinger trainer. The subjects' exit level will be determined by going through a live training with video recording.

CONCLUSION

A HMD-based virtual environment system may provide a solution to the Stinger training problem, as the HMD provides a display system that provides a large field of regard, yet in a small, hence portable, device. The success of this system depends on a number of critical factors of which the display system and the corresponding physical interaction between the head and the weapon system is primary, then tracking performance and end-to-end system latency. The planned project will eliminate uncertainty on these factors.

Conclusions

As has been said in the introduction: The use of HMD technology in virtual environments for training simulation has always been recognised to be of great potential. So many have been proclaiming the infinite spectrum of applications that virtual environment technology will have in our daily lives. And so many are still waiting for real applications of this technology to appear.

The Forward Air Controller training and Stinger team training applications in the military field have made us confident that real applications of HMD-based virtual environment systems do exist. The Forward Air Controller training study has proven that this type of system is accepted by the military users as a useful training tool.

ABOUT THE AUTHOR

Frido Kuijper is a research scientist in the Command & Control and Simulation Division at TNO-FEL. He has been involved in VE technology and its military applications ever since the R&D program in this field started in the early nineties. He is leader of the project on the application of VE technology for FAC training and several other VE related projects for the Dutch armed forces. He holds an M.Sc. in Computer Science from Delft University of Technology (NL) and specialises in visual simulation, display systems and tracking systems.

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